The Dimension of Ice Crystals in Natural Clouds

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ABSTRACT

The dimensions of over 1500 natural ice crystals occurring in orographic and cumuliform clouds were obtained by studying the replicated crystals under microscopic magnification. Empirical relationships describing their dimensions over a larger range of sizes than previously reported have been developed.

1. Introduction

Inherent to understanding the precipitation mechanism in natural clouds is the study of the elements formed by the precipitation mechanism in question. For example, the relationship between the shape and type of natural ice crystals and the temperature at which they have grown appears to be sufficiently well established (Mason, 1953; Nakaya, 1954; Magono and Lee, 1966). However, within each category of crystal type there has been no *extensive* study of the variation in the ice crystal dimensions, except for the work of Ono (1969). An insight to the variation in the dimensions of ice crystals can serve to validate or improve various growth theories for ice crystal formation within natural clouds. Recently, Jayaweera and Cottis (1969) have demonstrated that the fall velocity and effective density of ice crystals are profoundly affected by both the diameter and thickness of plane ice crystals. Such information concerning the dimensions (length, diameter and thickness) of ice crystals is not extensive.

In order to satisfy these needs, the dimensions of natural ice crystals occurring in orographic and cumuliform clouds were studied and the results are reported in this paper.

2. Procedures

During the autumn of 1967, a close scrutiny of the prevailing ice crystal climatology within the Elk Moun-

Table 1. A summary of the empirical dimensional relationships for a variety of crystal types identified as to type and temperature (°C) habitat according to Magono and Lee (1966). Units are in microns and dimensions are h, height; d, diameter; W, width; L, length.

Code	Crystal type	Temperature regime	Dimensional relationship
Pla	Hexagonal plate	-10 to -13; -17 to -20	$h=2.020\ d^{0.449}$
P1b	Plate with sector-like branches	-10 to -13; -17 to -20	
P2e	Plate with simple extensions	-13 to -20	
P2f	Plate with sector-like extensions	-13 to -20	
P1c	Crystal with broad branches	-13 to -17	$h=2.028\ d^{0.431}$
P1d	Stellar	-13 to -17	
P2a	Stellar with end plates	-10 to -17	
P2b	Stellar with sector ends	-10 to -17	
P1e	Ordinary dendritic	-13 to -17	$h=2.801\ d^{0.377}$
P1f	Fernlike crystal	-13 to -17	
P2c	Dendritic crystal with end plates	-10 to -17	
P2g	Plate with dendritic extensions	-13 to -20	
P3c	Four-branched crystal	-13 to -17	
P4b	Dendritic crystal with 12 branches	-13 to -17	
C1g	Solid thick plate	-9.5 to -11; -18.5 to -20	$h=0.402\ d^{1.018}$
C1h	Thick plate of skeleton form	-9.5 to -11; -18.5 to -20	
C1e	Solid column	-8 to -10; <-20	$W=-8.479+1.002\ L-0.00234\ L^2$; $L\leqslant 200\ \mu$
C1f	Hollow column	-8 to -10; <-20	$W=11.3\ L^{0.414}$; $L>200\ \mu$; $h=0.866\ W$
N1a	Elementary needle	-4 to -6	$W=1.099\ L^{0.61078}$
N1e	Long solid column	-6 to -8	$h=W$

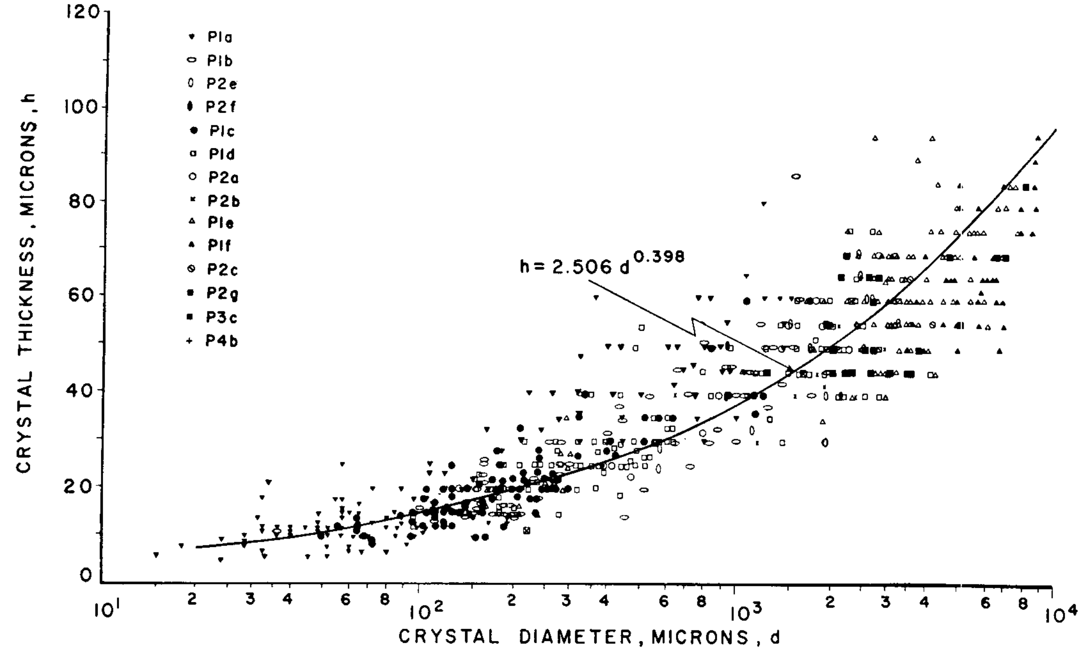

FIG. 1. The observed diameter-thickness relationship for the spectrum of plate crystals. The crystal identification code is taken from Magono and Lee (1966).

tain orographic cloud was initiated in an attempt to isolate some features of the natural precipitation processes. The isolated cap cloud was selected for study at that time because it is perhaps the simplest of the orographic clouds and, therefore, presents an opportunity for investigating some of the important cloud processes. Furthermore, the location of the high mountain observatory (3350 m MSL) affords an excellent opportunity for studying the full spectrum of ice crystals produced by large general storm situations as well as those resulting from the isolated cap cloud. Additional data for columnar and needle type crystals were obtained from growing summer cumulus clouds.

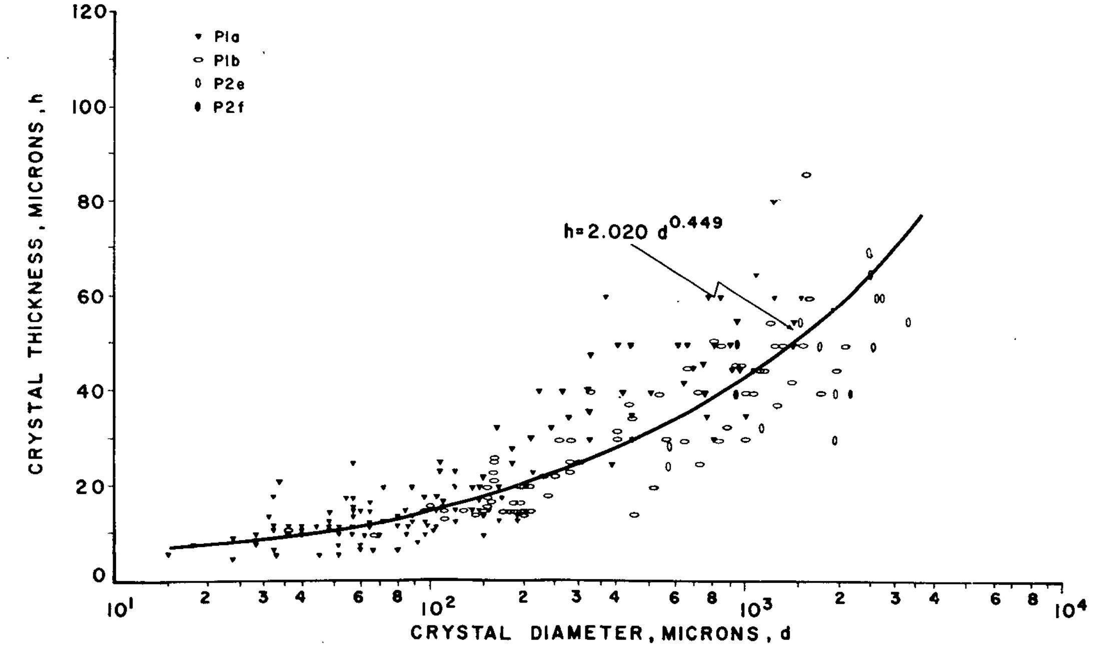

FIG. 2. The observed diameter-thickness relationship for plate crystals in which the dominant shape characteristic is hexagonal. The crystal identification code is taken from Magono and Lee (1966).

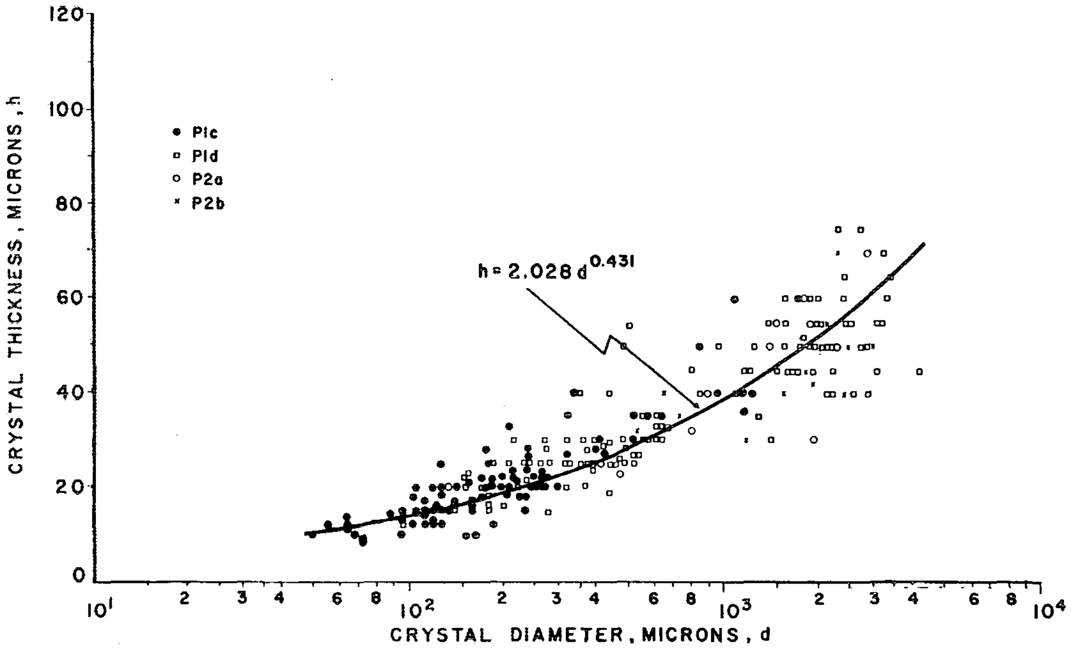

Fig. 3. The observed diameter-thickness relationship for plate crystals in which the dominant shape characteristic is stellar. The crystal identification code is taken from Magono and Lee (1966).

Individual ice crystals have been collected, replicated and studied under both high and lower power microscopes. Since the ice crystals within the cap cloud may be replicated at very slow impact speeds, the breakage of even the most fragile of dendritic crystals is not likely.

The ice crystal replicas were viewed under a microscope, generally with a 100× magnification. To study the relationship between the diameter and thickness of plate crystals and the length, width and thickness of columnar crystals, the thickness dimension was measured by focusing on both the top and bottom of the ice crystal replica and reading the displacement on the calibrated fine-adjustment of the microscope; this procedure has been followed by many investigators and

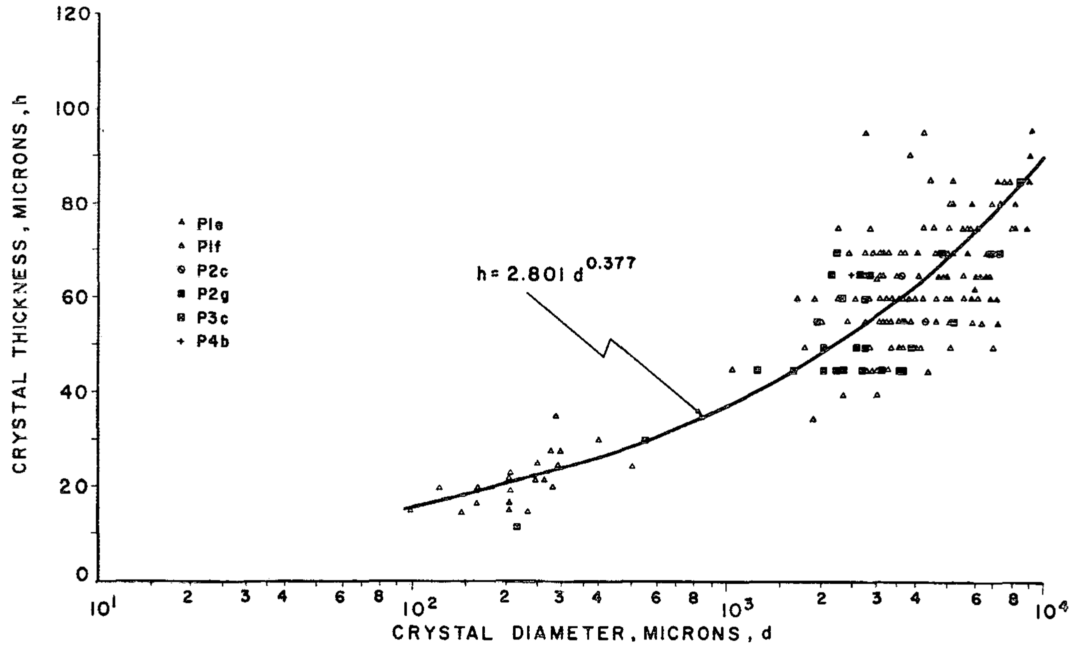

Fig. 4. The observed diameter-thickness relationship for plate crystals in which the dominant shape characteristic is dendritic. The crystal identification code is taken from Magono and Lee (1966).

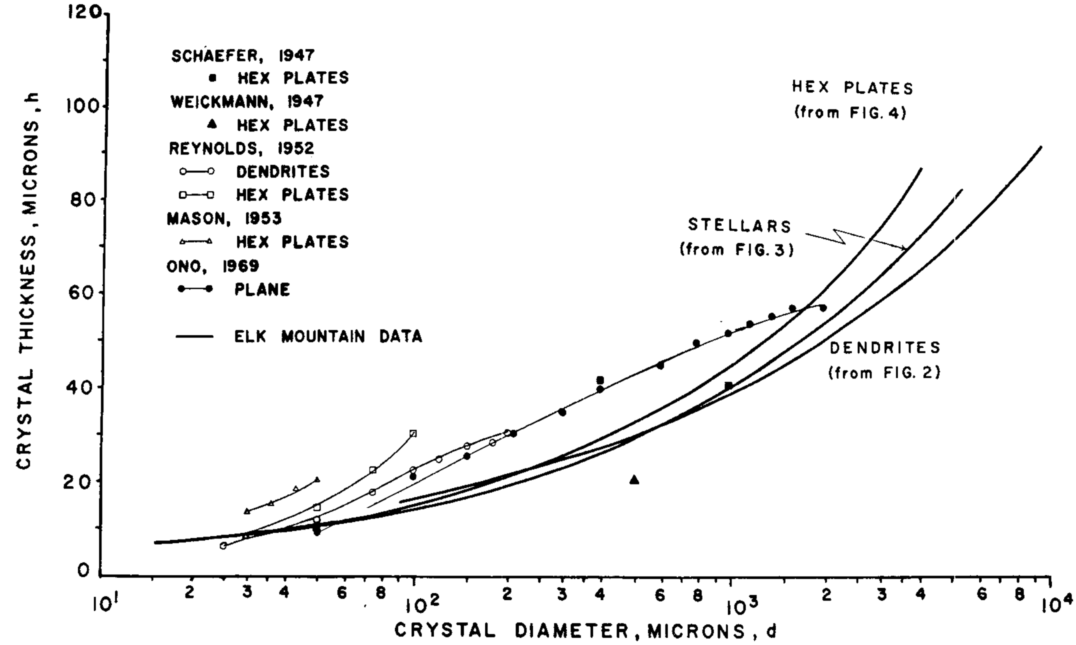

FIG. 5. A comparison of the other known diameter-thickness relationships for plate family crystals with data obtained from this study.

was first suggested by Schaefer (1947). By performing repeated focusings on the top and bottom of items of known thickness, the authors feel that thickness measurements can be determined to within ±10 μ. Certain of the larger crystals had accreted droplets; however, this riming did not prevent determination of the thickness to within ±10 μ.

In order to classify the myriad of ice crystals sampled during the course of this study, the Magono and Lee (1966) classification of snow crystals has been employed throughout this paper. In the opinion of the authors, Magono and Lee give the most comprehensive classification available at this time.

The empirical relationships for the ice crystal data were derived by fitting polynomial or power functions to the diameter and thickness data for plate crystals and length, width and thickness data for columnar crystals.

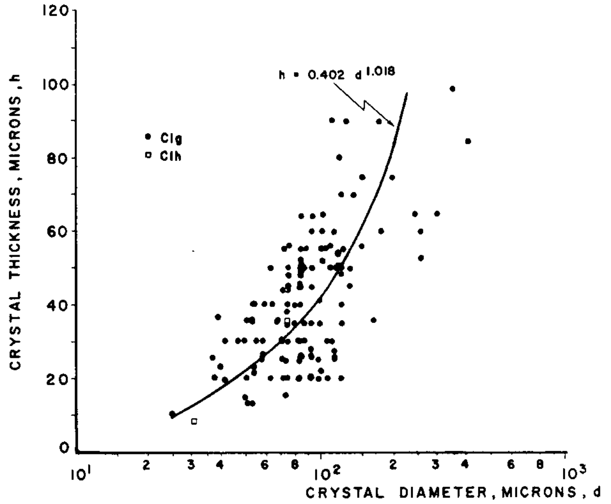

FIG. 6. The observed diameter-thickness relationship for crystals of the thick plate variety. The crystal identification code is taken from Magono and Lee (1966).

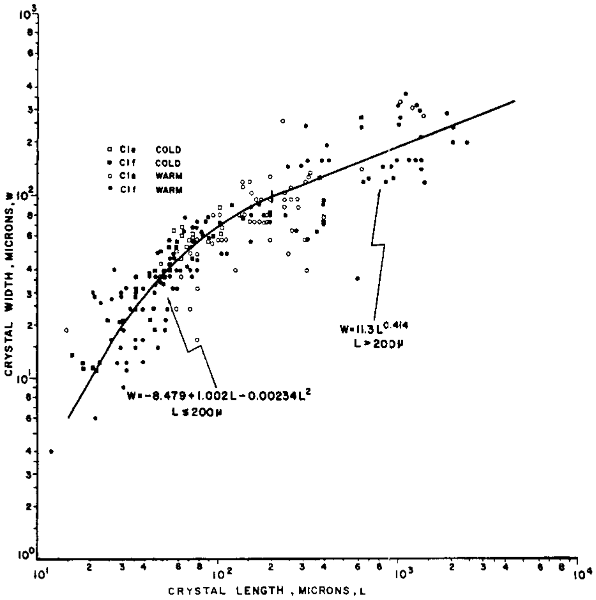

FIG. 7. The observed length-width relationship for columnar crystals. The crystals are stratified into cold (<−20C) and warm (−8 to −10C) regimes, depending on their growth environments. The crystal identification code is taken from Magono and Lee (1966).

Using a least-squares technique, the best fit equations were obtained for the data and are shown in Figs. 1–14, and in Table 1.

3. Results

a. Plates

The observed diameter-thickness relationship for the entire spectrum of plate crystals [see Magono and Lee (1966) for the exact definition of coded types] is presented in Fig. 1. The relationship between the diameter and thickness for plate crystals within the size ranges observed is represented by a power function. The various members of the plate family were partitioned into specific groups according to their dominant shape characteristics, e.g., hexagonal plates, stellars and dendrites. The relationships for these specific types are shown in Figs. 2–4, respectively.

Ono (1969) suggested that the thickness of plane ice crystals approached limiting values of 50–60 μ as the diameter of the ice crystal increases; however, Ono's data did not include crystal diameters $>2200\,\mu$. The data presented in Figs. 1–4 indicate that when the crystal diameter exceeds $2400\,\mu$, the thickness can be greater than $50\,\mu$. For example, dendritic crystals approaching $10^4\,\mu$ in diameter possess thicknesses near $90\,\mu$.

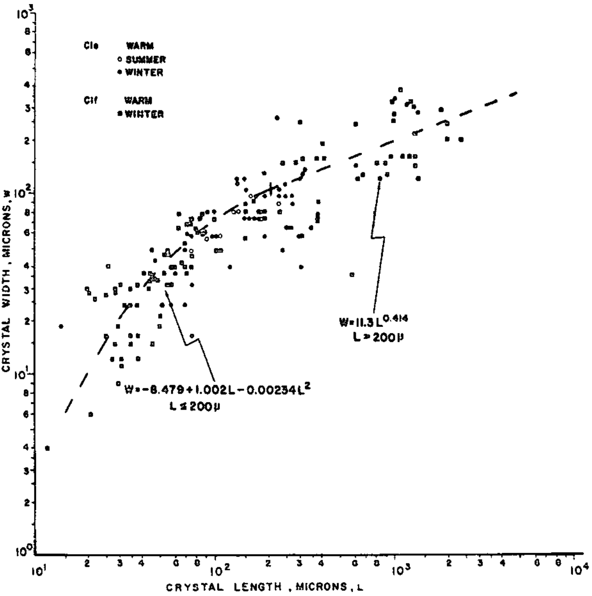

FIG. 8. The observed length-width relationship for columnar crystals sampled only in a warm (−8 −10C) growth environment. The crystal identification code is taken from Magono and Lee (1966).

Earlier data relating diameters and thicknesses for plate crystals (Schaefer, 1947; Weickman, 1947; Reynolds, 1952; Mason, 1953; Ono, 1969), together with observations of this study, are presented in Fig. 5. It can be seen that suitable agreement is attained with previous investigators over the size ranges considered.

An examination of the combined data presented in Fig. 5 reveals that each of the plate type crystals

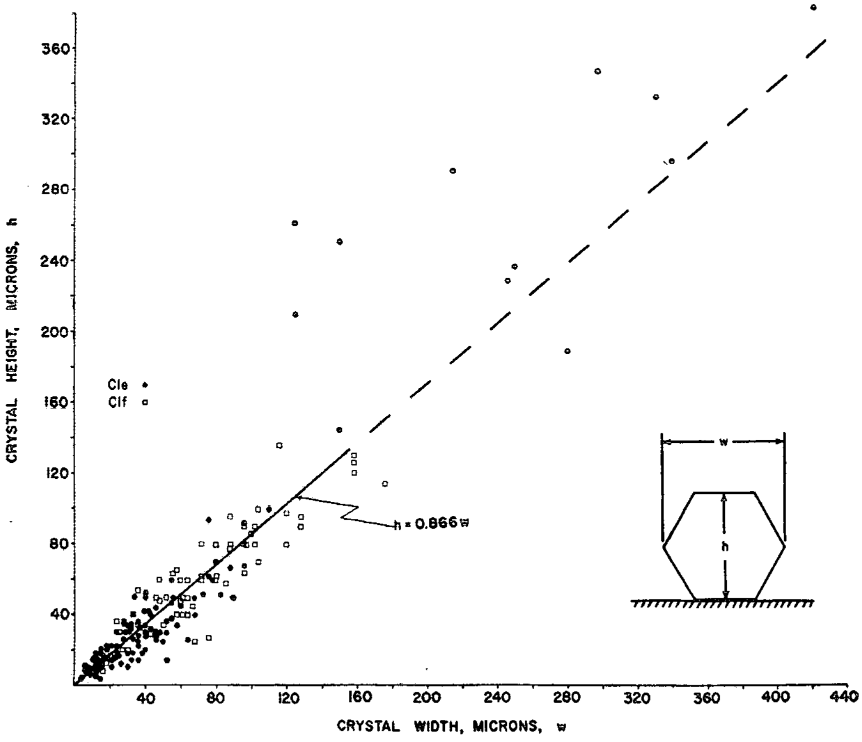

FIG. 9. The observed width-height relationship for columnar crystals.

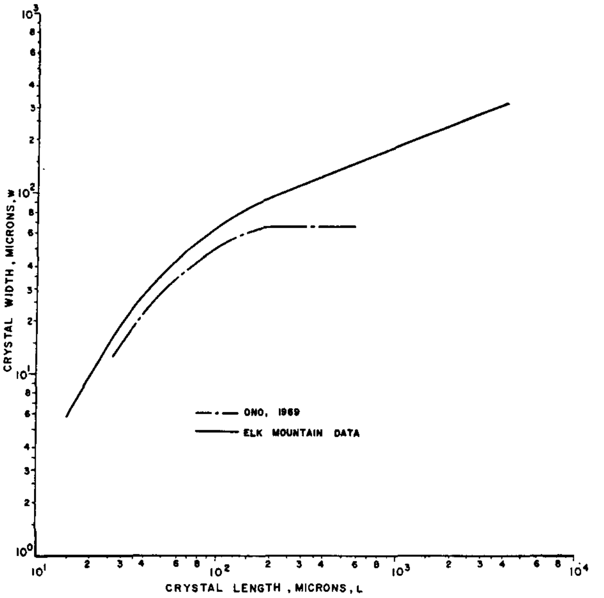

FIG. 10. A comparison of the length-width relationships for columnar crystals between the data of Ono (1969) and data obtained from this study.

(hexagonal plates, stellars, dendrites) maintains similar diameter-thickness relationships up to $\sim 1000\,\mu$ in diameter. When the diameter exceeds $1000\,\mu$ the thickness relationships diverge, with the thicker crystals being hexagonal plates followed by stellars and dendrites. In addition, Hallett (1965) suggested constant thicknesses for plane crystals up to a diameter of $100\,\mu$; this is in agreement with the findings presented in Fig. 5 in which plate crystals maintain a nearly constant thickness up to $100\,\mu$ in diameter.

b. Thick plates

The observed diameter-thickness relationship for crystals of the thick plate variety is given in Fig. 6. These data indicate that when thick plates attain diameters near $100\,\mu$ the dominant growth is in the thickness dimension.

c. Columns

The observed length-width relationship for columnar crystals which are stratified into cold (<-20C) and warm (-8 to -10C) regimes are presented in Fig. 7. The observed length-width relationships for those columnar ice crystals which were obtained in only the warm growth environments (winter and summer) are presented in Fig. 8. The summertime data were obtained by replicating crystals during penetrations of the top portion (-8 to -10C) of growing cumulus clouds. The dashed line shown in Fig. 8 is the same empirical relationship as given in Fig. 7. Thus, these data suggest the length-width relationship for columns within the -8 to -10C growth environment is similar whether the crystal was grown in a winter orographic cloud or in a summer growing cumulus cloud.

Inspection of columnar type crystals indicated that the shaft or column portion of the crystal was hexagonal in shape. In order to substantiate this apparent shape, the height-width relationship was developed and is presented in Fig. 9; it indicates that for crystals $\lesssim 160\,\mu$ in width the columns are hexagonal in shape. For crystals having a width $>160\,\mu$, the accretion of droplets on the crystal may prevent reliable width and/or height measurements.

In order to realistically compare the columnar crystal data of Ono (1969) with the observations of this study,

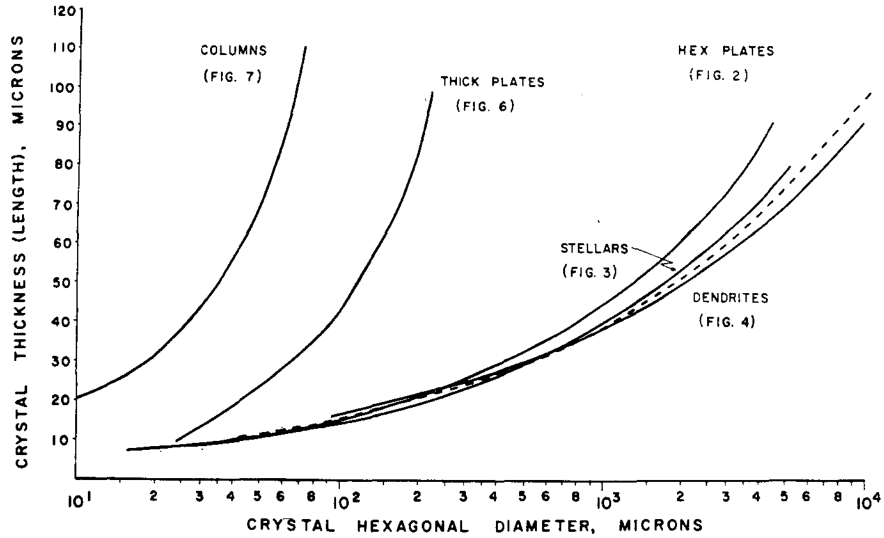

FIG. 11. A comparison of the hexagonal diameter-thickness (length) relationships for hexagonal plates, stellars, dendrites, thick plates and columnar-type crystals. The dashed curve represents the composite plate family diameter-thickness relationship as shown in Fig. 1.

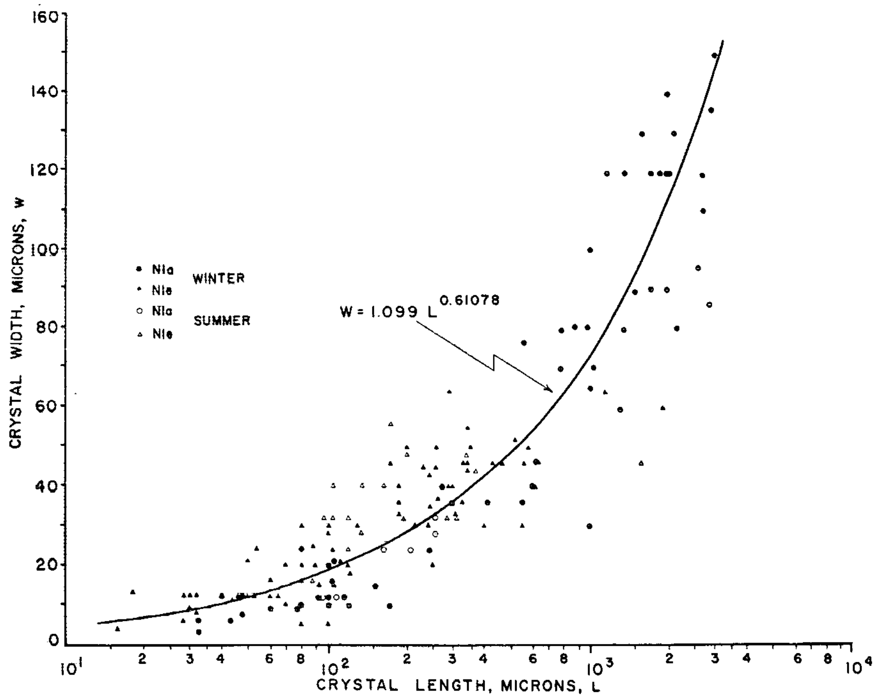

FIG. 12. The observed length-width relationship for needle crystals. The crystal identification code is taken from Magono and Lee (1966).

a length-width relationship was developed using Ono's data; this comparison is given in Fig. 10. Ono's data suggest that columnar crystals reaching lengths of 200 μ stabilize in width at 60 μ. The data shown in Figs. 7 and 8 clearly indicate that the columns observed in this study grew to widths well in excess of 60 μ.

A comparison of the hexagonal diameter-thickness (length) relationships for hexagonal plates, stellars, dendrites, thick plates and columnar-type crystals is given in Fig. 11. The relationships can be interpreted in view of the laboratory experiments of Hallett (1961), who suggested that, as the crystal growth modes proceed from columnar to thick plate to hexagonal plate to stellar and/or dendrites (i.e., variation in temperature habitat), there is a corresponding variation in velocity of the step propagation between the base and prism faces of crystals. According to Hallett (1961), Hobbs and Scott (1965) and Hobbs (1967), in the temperature environment from −5 to −10C growth is more rapid on the basal face, while in the regions from −10 to −20C the growth is dominant on the prism face. For the varieties of ice crystal types observed within natural cloud structures there is qualitative agreement with laboratory experiments for the dominant growth directions (basal or prism faces) within the −5 to −20C temperature regimes.

d. Needles

Observations of length and width dimensions for needle-type crystals obtained during the study are presented in Fig. 12. The crystals which are labeled "winter" were obtained from orographic clouds and those labeled "summer" by penetrating the tops of growing cumulus clouds in the −5 to −8C temperature range.

To ascertain the shape of the needle crystals, the height-width dimensions were compared, the results being given in Fig. 13. These data suggest that the height-width dimensions are typically the same; therefore, in all probability the crystals are cylindrically

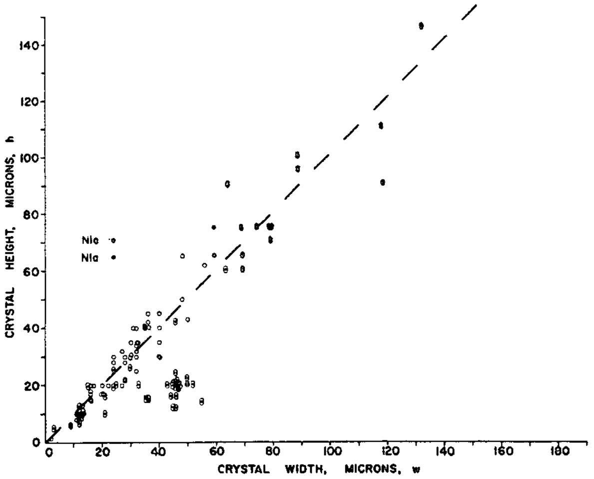

FIG. 13. The observed width-height relationship for needle crystals.

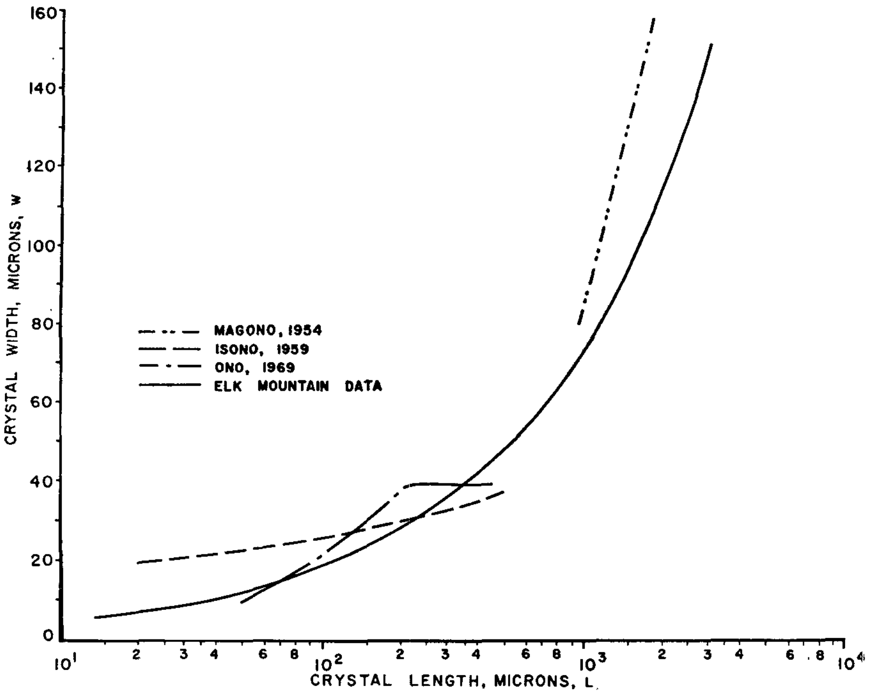

FIG. 14. A comparison of other known length-width relationships for needle crystals with data obtained in this study.

shaped as proposed by Nakaya (1954) and Magono and Lee (1966).

Other length-width relationships for needle crystals have been found. Thus, Magono (1954) investigated length-width relationships for needles in excess of $10^3\,\mu$ in length, while Isono (1959) and Ono (1969) examined crystals up to $500\,\mu$ in length. A comparison of these earlier data with observations from this study (see Fig. 14) confirms the earlier findings and completes the definition of the relationship.

4. Summary

Natural ice crystals occurring in both orographic and cumuliform clouds were studied and empirical relationship describing their dimensions were developed. These equations are summarized in Table 1.

The reader should be cautioned not to apply the equations developed in this study beyond the size ranges observed for any of the crystal types.

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